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Projectile Dispersion of a Marker Ball Launcher

by Peter J. Fazio

ARL-TR-3319 October 2004

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14. ABSTRACT

The Weapons Technology Analysis Branch of the Ballistics and Weapons Concepts Division, Weapons and Materials Research Directorate of the U.S. Army Research Laboratory conducted a test of the firing ability of a marker ball launcher mounted on a robotic research laboratory vehicle. The robotic vehicle was used as a technology demonstration platform for autonomous and semi-autonomous behaviors. Some of the behaviors included the ability to return fire against enemy targets. In the interest of safety and simplicity, it was decided that a marker ball launcher would be used as the robot's "weapon" system. A fully integrated marker ball launcher and turret assembly, the return fire simulator (RFS), was mounted on the robotic vehicle. The RFS mounts a 0.68-inch caliber, 16-inch-long launcher barrel onto a Directed Perceptions pan-and-tilt assembly. Some of the autonomous robotic behaviors require the robotic vehicle to fire a specified number of rounds to achieve a 90% probability of hit (pHit). To meet this requirement, an estimate of the launcher round dispersion, based on the range to the target, was needed. A test was developed to determine an estimate of the number of rounds required to achieve a 50%, 75%, 90%, 95%, and 99% pHit against a target of a specified cross-sectional size at various ranges. The test ranges were 20, 40, 60, and 80 feet from the muzzle of the launcher to the target board. At each range, 20 rounds were fired and their impact points were recorded. For each round fired, the optical aim point, produced by a class II laser, was recorded. The data were collected and analyzed to generate the azimuth (x coordinate) error and elevation (y coordinate) error and the total (x and y coordinate) error. The statistical means and standard deviations of these errors and of the muzzle velocities were calculated. The means of the azimuth error and elevation error were used to calculate the azimuth and elevation angular offsets, respectively. These data and the target cross-sectional size were used to calculate the number of shots required to achieve the probabilities of hit at the four target ranges.

15. SUBJECT TERMS

dispersion; launcher; marker ball; pHit

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1. Introduction

The Weapons Technology Analysis Branch of the Ballistics and Weapons Concepts Division, Weapons and Materials Research Directorate, U.S. Army Research Laboratory (ARL) conducted a test of the firing ability of a marker ball launcher mounted on a robotic research laboratory vehicle. The robotic vehicle, an iRobot all-terrain research vehicle (ATRV) shown in figure 1, was used as a technology demonstration platform for autonomous and semi-autonomous behaviors. Some of the behaviors included the ability to return fire against enemy targets. The ability to return fire necessitated that some form of weapon system be implemented on board the robotic vehicle to properly evaluate the behavior.

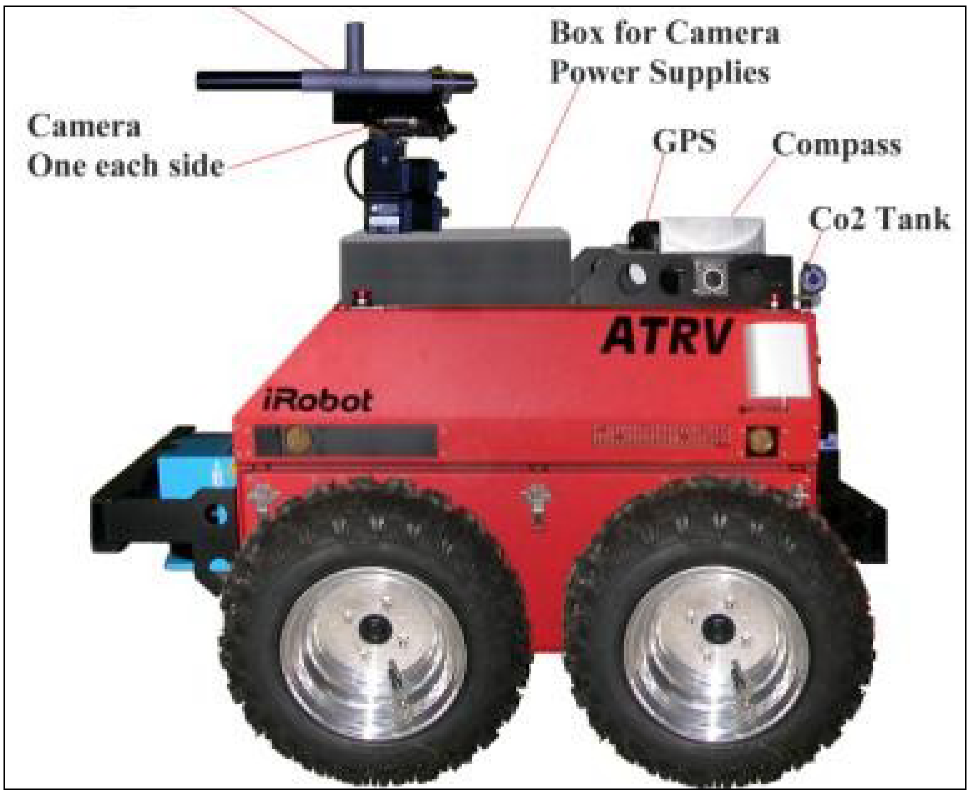

Figure 1. All-terrain research vehicle.

In the interest of safety and simplicity, it was decided that a marker ball launcher (paintball gun) would be used as the robot's "weapon" system. A turret capable of azimuth and elevation changes was also needed for the marker ball launcher to allow the robotic vehicle to precisely point the launcher tube during targeting behaviors. A fully integrated marker ball launcher and turret assembly, the return fire simulator (RFS) shown in figure 2, was purchased from Bristlecone Corporation. The RFS is typically used as a stationary tactical training device for

military and law enforcement personnel. The RFS simulates enemy fire during close quarter tactical scenarios, such as military operations in urban terrain and law enforcement special weapons and tactics operations in urban dwellings. The RFS mounts a 0.68-inch caliber, 16-inch-long launcher barrel onto a Directed Perceptions, Inc., pan-and-tilt assembly. The standard trough-like paintball magazine was replaced with a vertical acrylic tube magazine in an effort to reduce the load on the turret drives. A low power class II laser was used as an optical pointing aid for targeting during the testing. The RFS launcher and turret assembly, along with the carbon dioxide propellant and regulator, were mounted on top of the ATRV to create a mobile autonomous robotic gun system surrogate.

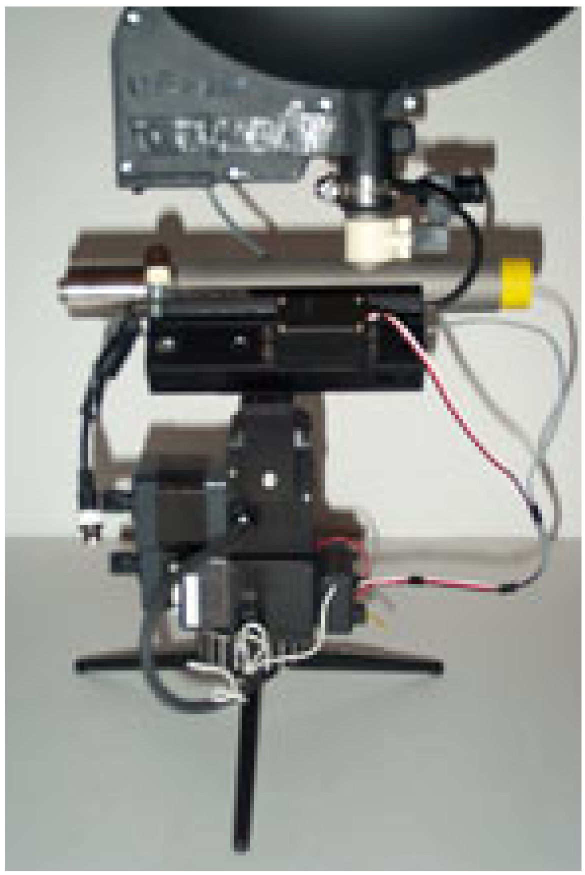

Figure 2. Return fire simulator.

Some of the autonomous robotic behaviors require the robotic vehicle to detect an enemy target, sight the weapon system on the target, and then fire a specified number of rounds to achieve a 90% probability of hit (pHit). To meet one of the requirements for these behaviors, namely, number of rounds to achieve 90% pHit, an estimate of the RFS launcher round dispersion based upon the range to the target was needed. A test was developed to determine an estimate of the number of rounds required to be fired to achieve a 50%, 75%, 90%, 95%, and 99% pHit against a target of a specified cross-sectional size at various close quarter ranges. The test consisted of a series of trials where the RFS was fired at a fixed target setup from four close quarter ranges.

The test ranges were 20, 40, 60, and 80 feet from the muzzle of the launcher to the target board. At each range, 20 rounds were fired and their impact points were recorded. For each round fired, the optical aim point, produced by the class II laser, was recorded and the launcher re-aimed when necessary. The projectile's muzzle velocity was also recorded for each round fired via a radar chronograph, shown in figure 3. The data were collected and analyzed to generate the azimuth (x coordinate) error and elevation (y coordinate) error and the total (x and y coordinate) error. The statistical means and standard deviations of these errors and of the muzzle velocities were calculated. The means of the azimuth error and elevation error were used to calculate the azimuth and elevation angular offsets, respectively. These data and the target cross-sectional size were used to calculate the number of shots required to achieve the probablities of hit at the four target ranges.

Figure 3. Radar chronograph.

2. Procedures

The ATRV robot, which was outfitted with the RFS projectile launcher and a class II laser, was used as the surrogate weaponized autonomous robotic vehicle to evaluate the system's ability to achieve a probability of target hit within a specified number of shots fired. The ATRV, which is manufactured by iRobot Corporation, is a small, lightweight wheeled research robot. The vehicle is approximately 4 feet long, 3 feet wide, and 2.5 feet high and weighs 250 pounds. The chassis is a four-wheeled, skid-steered platform employing battery-powered electric drive motors. The RFS is a projectile launcher that uses compressed carbon dioxide propellant. The launcher tube is 16 inches long with a 0.68-inch diameter bore. The propellant is regulated to maintain a muzzle velocity of approximately 300 feet per second. The projectiles used for this

test were made of hard nylon and had a mass of approximately 28 grains. The launcher is mounted to a turret assembly comprised of a pan-and-tilt unit, manufactured by Directed Perceptions, Inc. A class II laser, with a maximum power output of less than 1 milliwatt, was mounted to the launcher barrel to allow for optical aiming of the RFS. The specified target size for the pHit calculations was a 3-foot by 3-foot square, which reasonably represents the cross-sectional area of the target vehicle. The target vehicle for the autonomous behavior being evaluated was a wheeled research robot that had a size similar to the ATRV. A 4-foot by 4-foot square target box, shown in figure 4, was constructed. This size target was assumed to be large enough to accept the total shot dispersion pattern of the launcher for the required test ranges.

Figure 4. Target box.

The target region was made from a heavy weight craft paper that was held in tension across the target box to allow for the projectiles to make a clear perforation upon impact. The horizontal and vertical sides of the target box had graduated rules attached to allow for accurate measuring of the azimuth and elevation optical laser aim points and projectile hit points. The testing began upon completion of the final assembly of the various pieces of hardware. The ATRV with its mounted projectile launcher was emplaced at the initial test range from the target box. A radar chronograph was set up below and slightly ahead of the launcher tube's muzzle to record the projectile muzzle velocity. We aimed the launcher by observing the red laser spot generated by the class II laser, via a remote mounted joystick controlling the turret drives. The laser spot image produced on the target area was measured to record its azimuth and elevation position. The launcher was pressurized with propellant and a projectile fired at the target. The projectile

hit point perforation through the craft paper was measured to record its azimuth and elevation position. The projectile's muzzle velocity was measured by the radar chronograph and recorded.

Twenty shots were fired (in total) at the first test range, and the aim points, hit points, and muzzle velocities were measured and recorded for each shot. The procedures were duplicated for the successive test ranges. The data were analyzed for each group of shots at a particular test range and then analyzed across the series of test ranges to develop a dispersion trend based on range to the target. We calculated an azimuth and elevation error for each test shot by subtracting the aim point from the actual hit point. A mean azimuth error, a mean elevation error, and a total error was calculated for the group of 20 shots for each of the four test ranges. The standard deviations for the azimuth and elevation errors were calculated, as well, within the groups of shots. We calculated the azimuth angular offset of the launcher by taking the inverse tangent of the azimuth error mean divided by the test range. The elevation angular offset was calculated similarly with the elevation error mean and the test range. Two sets of pHit numbers were calculated for these data: the first, an uncorrected set of pHit numbers based on the raw data, and second, a set of corrected pHit numbers, where the azimuth and elevation biases were removed. Removal of the azimuth bias required that the azimuth error mean be subtracted from the azimuth errors. The resulting corrected azimuth errors were then used to calculate the standard deviation for the corrected group of hit errors.

A similar procedure was applied to the elevation errors, with the elevation error mean to create a set of corrected elevation errors. The standard deviation of the set of corrected elevation errors was then calculated, as well. An algorithm was developed ([f]) that generated the number of shots required to achieve the various levels of pHit for each group of shots. The azimuth and elevation standard deviations of the group of shots, the azimuth and elevation standard deviations of the gun bias and the width and height of the target are entered in the algorithm to produce the pHit. The azimuth and elevation standard deviations of the gun bias, in this particular test, were always zero because a single launcher was used throughout the testing. The width and the height of the target were both 3 feet. The standard deviations of the uncorrected and the corrected azimuth and elevation errors were used as the input to the algorithm. The output generated by the algorithm was the number of shots required to achieve the probabilities of hit of 50%, 75%, 90%, 95%, and 99% for the uncorrected and corrected errors. The data are shown in appendix A.

3. Discussion

The data from this test show a fairly consistent tendency for the launcher to create a dispersion pattern bias in both azimuth and elevation (see figures 5 through 8). The elevation bias, which is negative across all target ranges, becomes fairly large at the longer ranges because of the lack of

[f] Algorithm developed by Dr. Joseph K. Wald, ARL, 2003.

a fire control compensating for increases in super-elevation based on range to the target. The muzzle velocities stayed quite consistent throughout the test with an overall mean of 308.6 feet per second and a standard deviation of 2.66 feet per second. The azimuth bias is positive for all the target ranges. There is a strong positive azimuth bias for all but the 80-foot range. The lower three target ranges show a consistent tendency to fire to the right of the aim point. The azimuth bias at the 80-foot range, while positive, is close to zero. It was observed during testing that the flight characteristics tended to be more erratic at the longest range, possibly causing the deviation from the general azimuth bias trend toward the right of the aim point. Notably, at the 80-foot range, a couple of shots hit above the aim point, producing a positive elevation error, thus giving more credibility to the conjecture that the erratic flight behavior may have influenced the trend of the data. The erratic flight behavior of some of the projectiles at the longest range may have been caused by manufacturing defects in the projectiles themselves. During the testing, an occasional shot was fired that passed through the target box backstop and impacted a solid surface, causing the nylon projectile to crack or split open. Upon inspection of the cracked open projectile, a void was typically found to be present inside. The void inside the nylon spheres tended to be of approximately the same volume, thus maintaining a consistent mass of 28 grains for each projectile, but was situated rather randomly about the sphere's geometric center. This offsetting of the void caused the projectile's center of mass to be situated away from the geometric center, as well. Having some projectiles with a non-centroidal center of mass likely contributed to the erratic flight behavior which was sometimes observed during firing at the longest range. To eliminate this variation, the dispersion testing could be redone with projectiles having no internal void or having a homogeneous density throughout the sphere.

The dispersion data were then run through the algorithm to generate the pHit numbers for the various ranges. When we look at the bar chart in figure 9, which shows the number of shots required to achieve the various pHit levels at the four ranges without correcting for the dispersion bias, it is clear that only one shot will be required to achieve a 99% probability of target hit at the ranges of 20 and 40 feet. The 60-foot range will only require one shot to achieve a 95% pHit but will require two shots to attain the 99% pHit level. The longest range, 80 feet, shows a linear increase in the number of shots required from two shots needed at the 50% pHit level to five shots needed at the 95% pHit level. A further increase to seven shots is needed to achieve the 99% probability of hit. When we look at the bar chart in figure 10, which shows the number of shots required to achieve the various pHit levels at the four ranges with correction for the dispersion bias, we see that only one shot is required to achieve the 99% pHit level for the 20-, 40-, and 60-foot target ranges. The 80-foot range requires only one shot to achieve the 50% pHit level, two shots to reach the 90% pHit level, three shots for the 95% pHit level, and four shots to achieve the 99% pHit level. The data on the bar charts clearly show that to achieve a relatively high probability of hit at close quarter ranges will require a minimal number of shots fired when the gun-pointing angles are adjusted to compensate for the dispersion biases. Further, it is likely that the number of shots required to achieve the specified pHit levels at the 80-foot

range would be reduced because of a tighter dispersion pattern, if projectiles with a consistent center of mass were used.

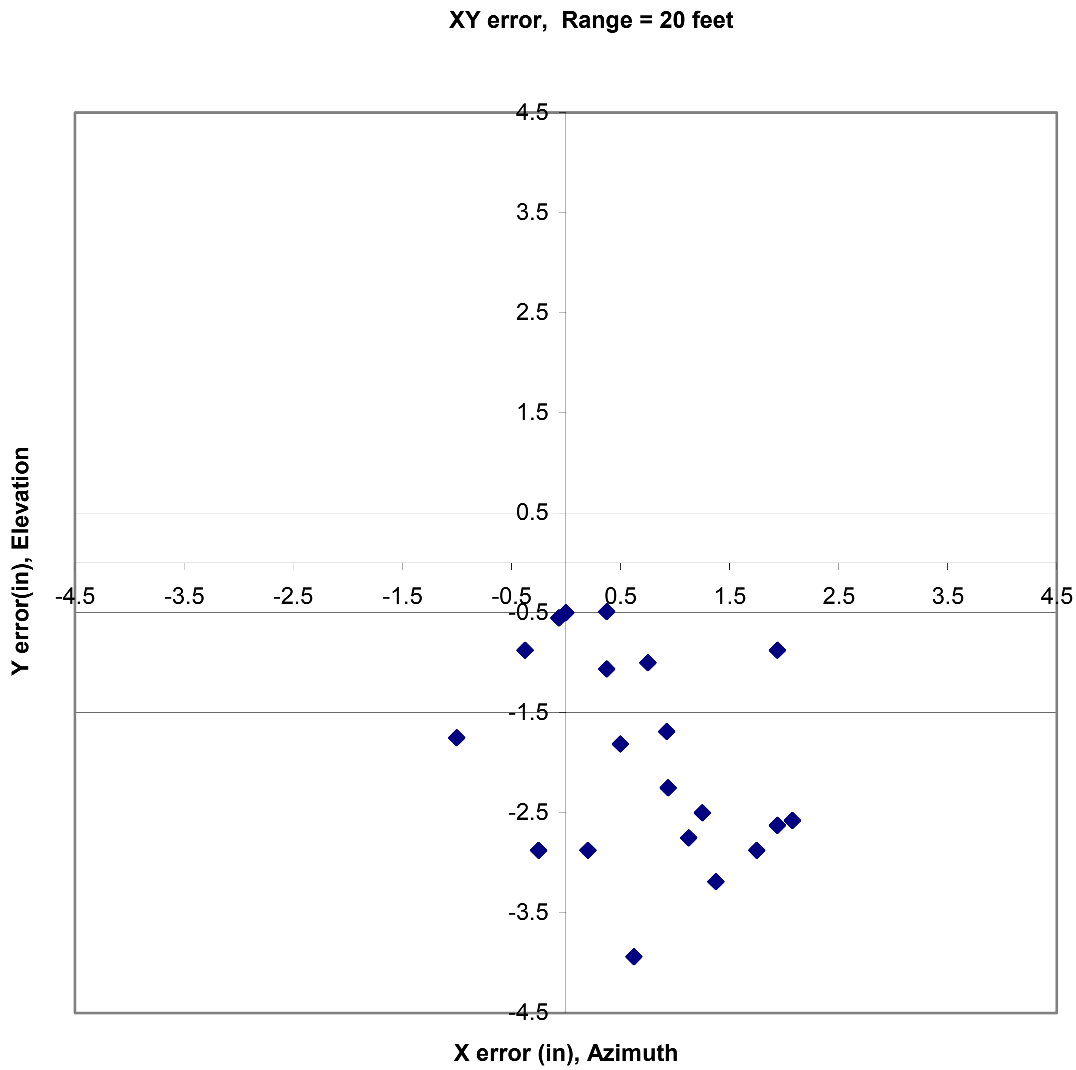

Figure 5. Dispersion pattern (range = 20 feet).

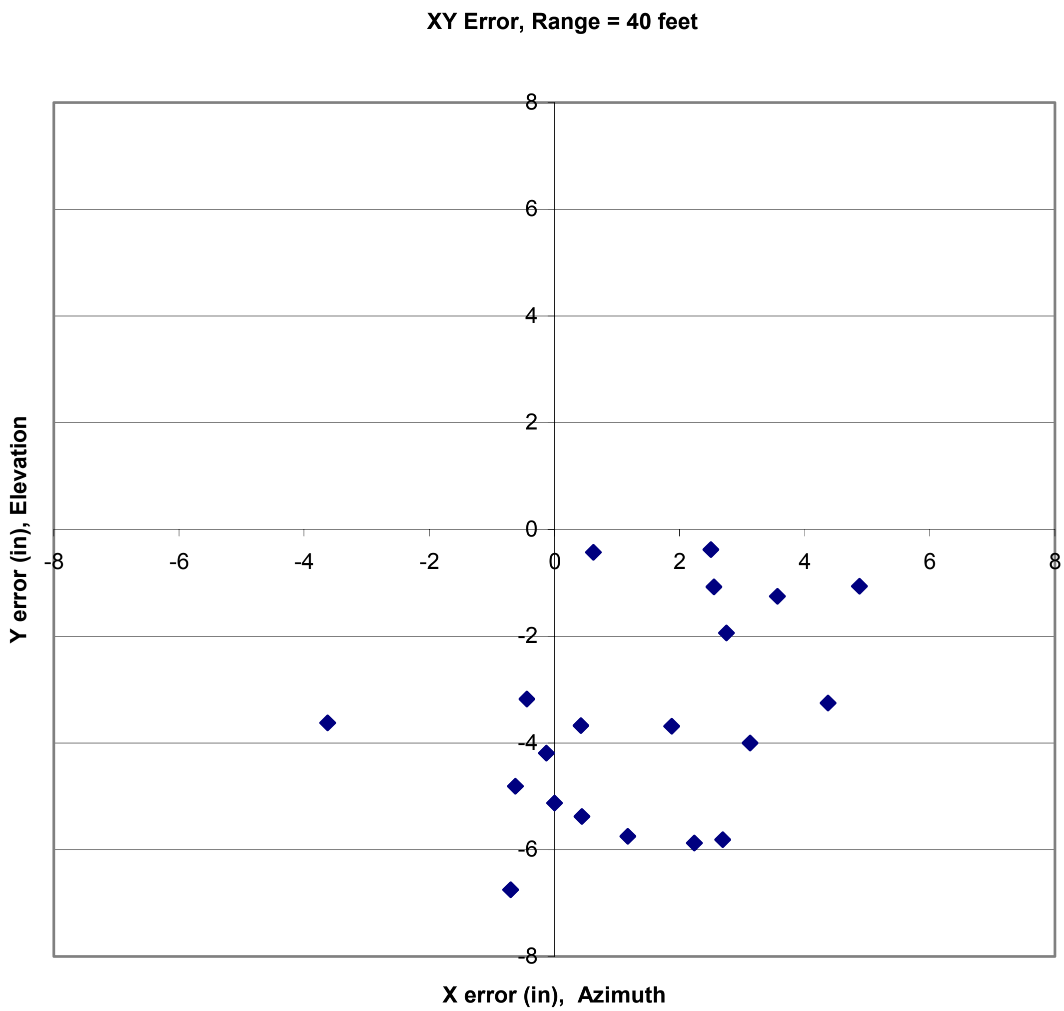

Figure 6. Dispersion pattern (range = 40 feet).

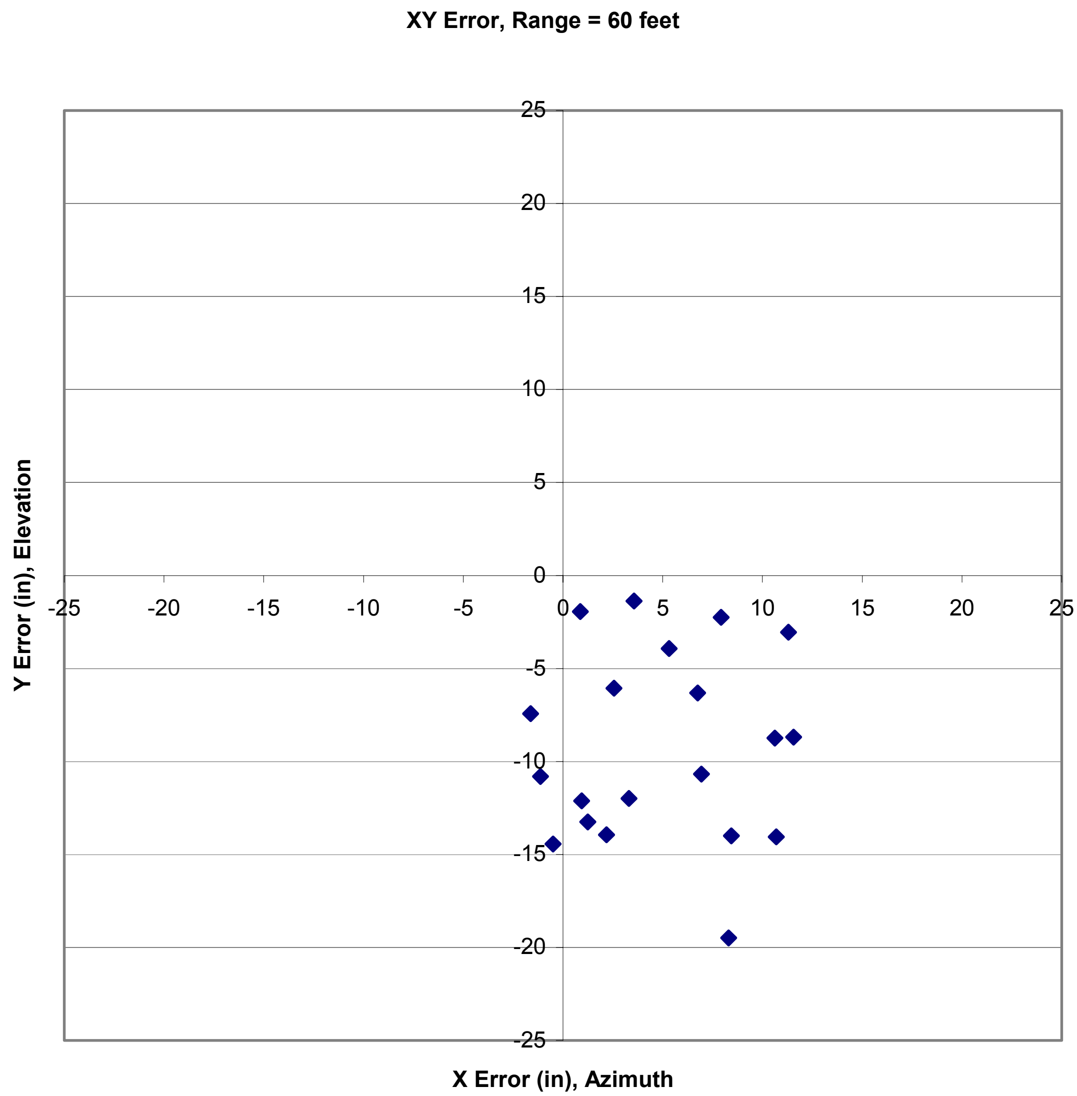

Figure 7. Dispersion pattern (range = 60 feet).

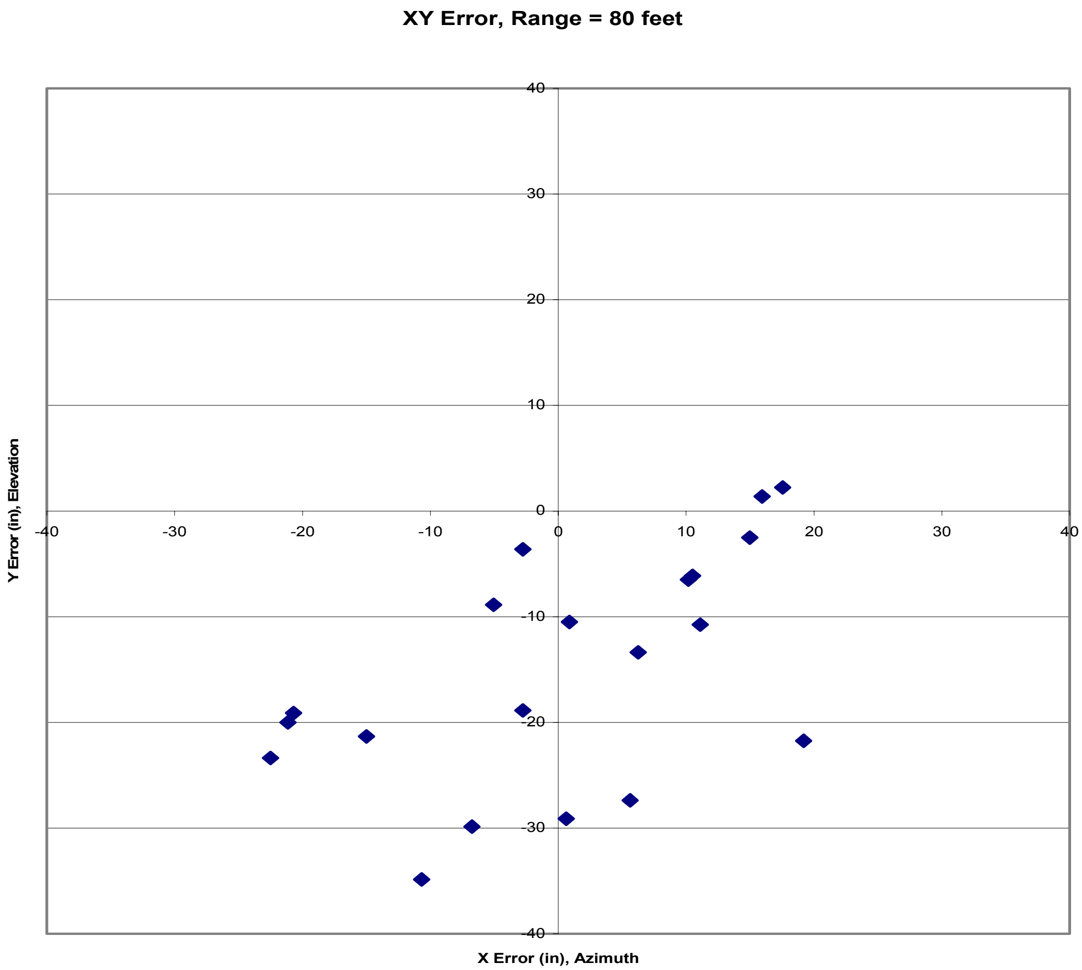

Figure 8. Dispersion pattern (range = 80 feet).

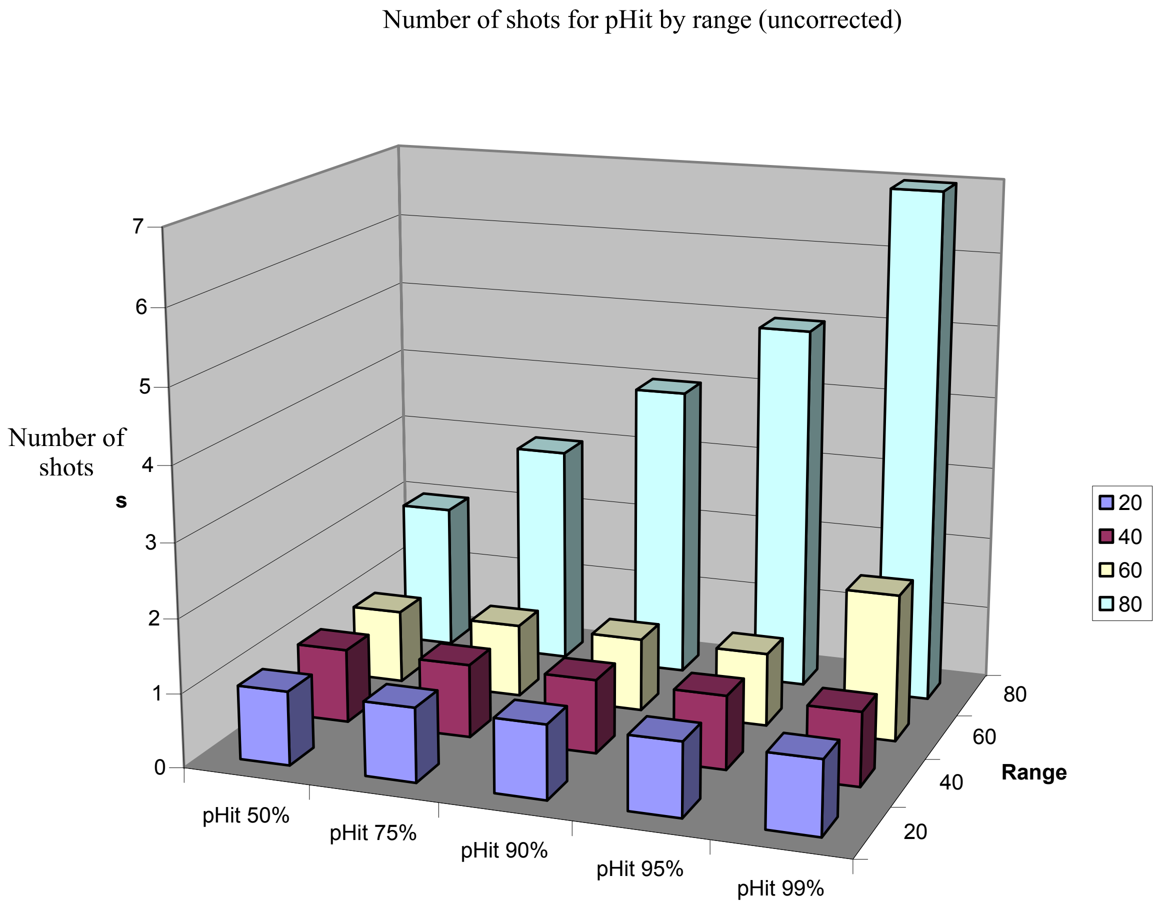

Figure 9. Number of shots, uncorrected pHit.

Number of shots for pHit by range (corrected)

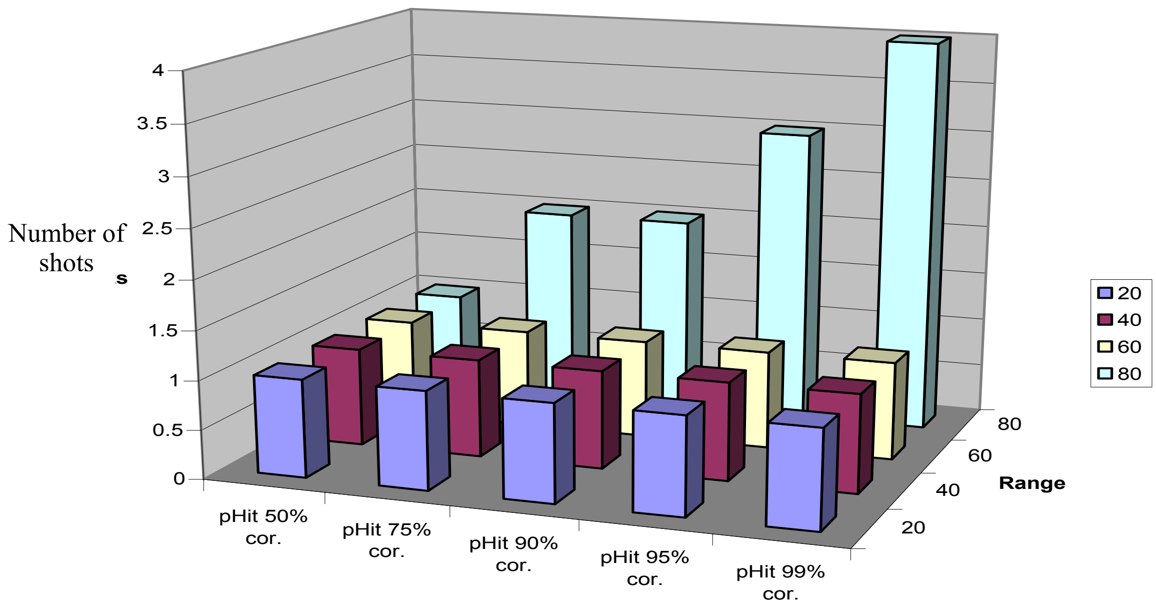

Figure 10. Number of shots, corrected pHit.

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4. Summary

A robotic vehicle, the iRobot ATRV, was used as a technology demonstration platform for autonomous and semi-autonomous behaviors. Some of the behaviors included the ability to return fire against enemy targets. The ability to return fire required the use of a weapon system on board the robotic vehicle to properly evaluate the behavior. The weapon of choice was an integrated marker ball launcher and turret assembly, the RFS, which is typically used as a stationary tactical training device for military and law enforcement personnel. The RFS was mounted on top of the ATRV to create a mobile autonomous robotic gun system surrogate. One of the autonomous behaviors requires the robotic vehicle to locate an enemy target, sight the weapon system on the target, and then fire a specified number of rounds to achieve a 90% probability of hit. To properly evaluate this behavior, the launcher's round dispersion at various ranges was needed to estimate the number of shots to achieve the specified level of pHit for a given size target.

A test was developed to estimate the number of rounds required to achieve a 50%, 75%, 90%, 95%, and 99% pHit against a target with a 3-foot by 3-foot cross-sectional size at four target ranges. The ranges used in the test were 20 feet, 40 feet, 60 feet, and 80 feet. Twenty rounds were fired at each range. For each round fired, the hit point and the aim point were recorded. We calculated an azimuth error and elevation error for each round by subtracting the respective aim point from the hit point. A mean azimuth error, a mean elevation error, and a total error was calculated for the group of 20 shots for each of the four ranges. The standard deviations of the errors were calculated, as well. The error means were used as the dispersion pattern biases. The pattern bias for all but the 80-foot range was low and to the right of the aim point. The 80-foot range showed only a slight bias to the right and a consistently low elevation bias. The number of shots required to achieve the various pHit levels over the four ranges was calculated with the azimuth and elevation error standard deviations, the azimuth and elevation standard deviations of the gun bias (in this case, it was always zero since we used a single launcher throughout the test), and the 3-foot by 3-foot target size. Two sets of pHit numbers were generated. A first set was based on the raw azimuth and elevation error standard deviations, and a second corrected set was based on azimuth and elevation error standard deviations where the error biases had been removed. The uncorrected data showed that only one shot will be required to achieve a 99% pHit at the ranges of 20 and 40 feet. The 60-foot range required one shot to achieve a 95% pHit but required two shots for 99% pHit. The 80-foot range shows a linear increase in the number of shots required from two needed for 50% pHit to five needed for 95% pHit. An increase to seven shots is needed to achieve 99% pHit. The corrected data showed that only one shot is required to achieve 99% pHit for the 20-, 40-, and 60-foot ranges. The 80-foot range requires one shot to achieve 50% pHit, two shots to reach 90% pHit, three shots for 95% pHit, and four shots to achieve the 99% pHit level.

The data show that to achieve a relatively high probability of hit at close quarter ranges will require a minimal number of shots fired when the gun-pointing angles are adjusted to compensate for the dispersion biases.

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Range(ft)	20
Date	10/9/2003
Time	13:00
Temp(F)	76
Ambient Pressure(mb)	1028
Projectile	
Type	Nylon
Caliber	0.68
Mass(g)	1.8

Shot #	Aim X(in)	Aim Y(in)	Hit X(in)	Hit Y(in)	Muzzle Velocity(ft/s)	X Error(in)	Y Error(in)	Total Error(in)
1	24.5	24.25	25.75	21.75	304	1.25	-2.5	2.795084972
2	24.25	24.25	25.375	21.5	310	1.125	-2.75	2.971216081
3	24.75	24.125	24.375	23.25	309	-0.375	-0.875	0.951971638
4	24.75	24.125	26.5	21.25	304	1.75	-2.875	3.365728004
5	24.8125	24.125	26.75	21.5	305	1.9375	-2.625	3.262595784
6	24.875	24.0625	25.5	20.125	307	0.625	-3.9375	3.986794608
7	24.9375	24	25.875	21.75	306	0.9375	-2.25	2.4375
8	24.75	24.25	25.5	23.25	310	0.75	-1	1.25
9	24.8125	24.125	26.75	23.25	306	1.9375	-0.875	2.125918919
10	24.875	24.125	23.875	22.375	305	-1	-1.75	2.015564437
11	24.875	24.0625	25.25	23	306	0.375	-1.0625	1.126734774
12	24.9375	24	24.6875	21.125	305	-0.25	-2.875	2.885849095
13	24.9375	24	24.9375	23.5	312	0	-0.5	0.5
14	24.675	24.25	24.875	21.375	305	0.2	-2.875	2.881948126
15	24.75	24.1875	26.125	21	305	1.375	-3.1875	3.471423519
16	24.675	24.25	26.75	21.675	304	2.075	-2.575	3.307000151
17	24.75	24.675	24.6875	24.125	308	-0.0625	-0.55	0.553539746
18	24.75	24.675	25.125	24.1875	306	0.375	-0.4875	0.61504573
19	24.75	24.5625	25.675	22.875	311	0.925	-1.6875	1.924391137
20	24.75	24.5625	25.25	22.75	304	0.5	-1.8125	1.88020112
Mean					306.6	0.7225	-1.9525	2.215425392
Standard Deviation					2.521486612	0.846680826	1.032566743	1.085823581
Azimuth Offset(deg)	-0.172483649							
Elevation Offset(deg)	0.46611475							

	pHit 50%	pHit 75%	pHit 90%	pHit 95%	pHit 99%
# of shots (uncorrected)	1	1	1	1	1
# of shots (bias removed)	1	1	1	1	1

Range(ft)	40
Date	10/16/2003
Time	14:00
Temp(F)	71
Ambient Pressure(mb)	1027
Projectile	
Type	Nylon
Caliber	0.68
Mass(g)	1.8

Shot #	Aim X(in)	Aim Y(in)	Hit X(in)	Hit Y(in)	Muzzle Velocity(ft/s)	X Error(in)	Y Error(in)	Total Error(in)
1	23.5	30.5	27.875	27.25	308	4.375	-3.25	5.450057339
2	23.5	30.5	24.675	24.75	307	1.175	-5.75	5.868826544
3	23	30.875	23	25.75	305	0	-5.125	5.125
4	23.125	30.75	25.675	29.675	313	2.55	-1.075	2.767331747
5	23.125	30.6875	25.8125	24.875	308	2.6875	-5.8125	6.403734262
6	23.125	30.675	23.75	30.25	311	0.625	-0.425	0.755810823
7	23.125	30.675	22.6875	27.5	311	-0.4375	-3.175	3.205000975
8	23.25	30.675	23.675	27	308	0.425	-3.675	3.699493209
9	23.3125	30.5625	22.6875	25.75	309	-0.625	-4.8125	4.852914717
10	23.3125	30.5	23.75	25.125	309	0.4375	-5.375	5.392775839
11	23.4375	30.4375	25.675	24.5625	308	2.2375	-5.875	6.286655013
12	23.3125	30.5	23.1875	26.3125	311	-0.125	-4.1875	4.189365256
13	23.375	30.5	26.125	28.5625	309	2.75	-1.9375	3.36398666
14	23.375	30.5	26.9375	29.25	307	3.5625	-1.25	3.775434578
15	23.375	30.5	25.875	30.125	310	2.5	-0.375	2.527968552
16	23.375	30.5	19.75	26.875	307	-3.625	-3.625	5.126524164
17	23.375	30.5	22.675	23.75	311	-0.7	-6.75	6.786199231
18	23.4375	30.5	26.5625	26.5	307	3.125	-4	5.075985126
19	23.4375	30.4375	25.3125	26.75	310	1.875	-3.6875	4.136820186
20	23.4375	30.4375	28.3125	29.375	303	4.875	-1.0625	4.989441978
Mean					308.6	1.384375	-3.56125	4.48896631
Standard Deviation					2.326053808	2.04507944	1.972662257	1.493225458
Azimuth Offset(deg)	-0.165247135							
Elevation Offset(deg)	0.425085106							

	pHit 50%	pHit 75%	pHit 90%	pHit 95%	pHit 99%
# of shots (uncorrected)	1	1	1	1	1
# of shots (bias removed)	1	1	1	1	1

Range(ft) 60
Date 10/17/2003
Time 12:03
Temp(F) 68
Ambient Pressure(mb) 1030
Projectile
Type Nylon
Caliber 0.68
Mass(g) 1.8

Shot #	Aim X(in)	Aim Y(in)	Hit X(in)	Hit Y(in)	Muzzle Velocity(ft/s)	X Error(in)	Y Error(in)	Total Error(in)
1	23 11/16	31 3/16	30 5/8	20.5	313	6.9375	-10.6875	12.74172526
2	23 11/16	31	32	11.5	309	8.3125	-19.5	21.19782197
3	23.5	35 1/8	24 3/4	21 7/8	308	1.25	-13.25	13.30883165
4	23.5	35 3/16	25 11/16	21 1/4	309	2.1875	-13.9375	14.10812045
5	23.5	35 3/16	24 3/8	33 1/4	316	0.875	-1.9375	2.125918919
6	23.5	35 1/8	21 7/8	27 11/16	315	-1.625	-7.4375	7.612951547
7	23 7/16	35 3/16	22 15/16	20 3/4	313	-0.5	-14.4375	14.44615541
8	23 7/16	35 3/16	34 3/4	32 1/8	313	11.3125	-3.0625	11.71970829
9	23.5	35 1/8	31 15/16	21 1/8	310	8.4375	-14	16.34599053
10	23.5	35 1/8	24 7/16	23	307	0.9375	-12.125	12.16118955
11	23.5	35 1/8	34 3/16	21 1/16	312	10.6875	-14.0625	17.66285828
12	23 7/16	35 1/16	34 1/16	26 5/16	311	10.625	-8.75	13.76419722
13	23 9/16	35	27 1/8	33 5/8	314	3.5625	-1.375	3.818642593
14	23.5	35	31 7/16	32 3/4	308	7.9375	-2.25	8.250236739
15	23.5	35	26 1/16	28 15/16	309	2.5625	-6.0625	6.581816808
16	23 7/16	35 1/16	30 3/16	28 3/4	312	6.75	-6.3125	9.241761534
17	23 7/16	35	35	26 5/16	306	11.5625	-8.6875	14.4625054
18	23 7/16	35	28 3/4	31 1/16	313	5.3125	-3.9375	6.612606332
19	23 7/16	35	26 3/4	23	309	3.3125	-12	12.4488014
20	23 7/16	35	22 5/16	24 3/16	309	-1.125	-10.8125	10.87086847
Mean					310.8	4.965625	-9.23125	11.47413542
Standard Deviation					2.783409496	4.3722489	5.076434688	4.685929301
Azimuth Offset(deg)	-0.395145617							
Elevation Offset(deg)	0.734559286							

	pHit 50%	pHit 75%	pHit 90%	pHit 95%	pHit 99%
# of shots (uncorrected)	1	1	1	1	2
# of shots (bias removed)	1	1	1	1	1

Range(ft)	80
Date	10/22/2003
Time	14:01
Temp(F)	69
Ambient Pressure(mb)	1010
Projectile	
Type	Nylon
Caliber	0.68
Mass(g)	1.8

Shot #	Aim X(in)	Aim Y(in)	Hit X(in)	Hit Y(in)	Muzzle Velocity(ft/s)	X Error(in)	Y Error(in)	Total Error(in)
1	23 1/8	36 7/8	18 1/16	28	312	-5.0625	-8.875	10.2173642
2	23.25	36.75	20.5	33 1/8	313	-2.75	-3.625	4.550068681
3	23 3/8	36.75	24.25	26.25	311	0.875	-10.5	10.53639526
4	23 7/16	36.75	2.75	17 5/8	311	-20.6875	-19.125	28.1733612
5	23 7/16	36.75	41	39	308	17.5625	2.25	17.70604152
6	21 7/8	36 9/16	6 7/8	15 1/4	305	-15	-21.3125	26.06190047
7	22	36.25	22 5/8	7 1/8	309	0.625	-29.125	29.13170524
8	21 7/8	44.25	0.75	24 1/4	304	-21.125	-20	29.09064497
9	21 7/8	44.25	28 1/8	30 7/8	308	6.25	-13.375	14.76323559
10	22 1/16	44.25	38	45 5/8	309	15.9375	1.375	15.99670376
11	22 3/16	44 1/8	41 3/8	22 3/8	305	19.1875	-21.75	29.00383865
12	22 1/4	44	15 1/2	14 1/8	304	-6.75	-29.875	30.62806107
13	22 1/8	44	27 3/4	16 5/8	307	5.625	-27.375	27.94693633
14	22 1/8	44	37 1/8	41 1/2	310	15	-2.5	15.20690633
15	22 1/4	43 7/8	19 1/2	25	313	-2.75	-18.875	19.07427915
16	22 1/2	43.75	33	37 5/8	310	10.5	-6.125	12.15588849
17	22 1/2	43.75	0	20 3/8	308	-22.5	-23.375	32.44442363
18	22 1/2	43.75	33 5/8	33	309	11.125	-10.75	15.47023351
19	22 9/16	43.75	32 3/4	37 1/4	310	10.1875	-6.5	12.08450066
20	22 9/16	43.75	11 7/8	8 7/8	303	-10.6875	-34.875	36.47585888
Mean					308.45	0.278125	-15.215625	20.83591738
Standard Deviation					2.999561371	13.3174715	10.90971989	9.119979698
Azimuth Offset(deg)	-0.016599363							
Elevation Offset(deg)	0.908039693							

	pHit 50%	pHit 75%	pHit 90%	pHit 95%	pHit 99%
# of shots (uncorrected)	2	3	4	5	7
# of shots (bias removed)	1	2	2	3	4

Range	pHit 50%	pHit 75%	pHit 90%	pHit95%	pHit 99%	pHit 50% cor.	pHit 75% cor.	pHit 90% cor.	pHit 95% cor.	pHit 99% cor.
20	1	1	1	1	1	1	1	1	1	1
40	1	1	1	1	1	1	1	1	1	1
60	1	1	1	1	2	1	1	1	1	1
80	2	3	4	5	7	1	2	2	3	4

Range	20	40	60	80
pHit 50%	1	1	1	2
pHit 75%	1	1	1	3
pHit 90%	1	1	1	4
pHit 95%	1	1	1	5
pHit 99%	1	1	2	7
pHit 50% cor.	1	1	1	1
pHit 75% cor.	1	1	1	2
pHit 90% cor.	1	1	1	2
pHit 95% cor.	1	1	1	3
pHit 99% cor.	1	1	1	4

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